ELEMENTARY ELECTRICAL TESTING

A COMPILATION, PRESENTING SOME OF THE MOST RECENT OPINIONS AND METHODS OF PROGRESSIVE PHYSICS INSTRUCTORS

MONOGRAPH B-2

SECOND EDITION, AUGUST, 1914

ISSUED FOR

SCIENCE TEACHERS IN EDUCATIONAL INSTITUTIONS

"Those who from a love of truth would pursue it for its own sake are so overworked with the drudgery of elementary teaching, and so poorly supplied with the implements of investigation, that it is not surprising that science has made comparatively *little* advance among us, but that, under existing conditions, it should have made so much."—JOSEPH HENRY.

(*Extract from a letter to the Committee of Arrangements of the Farewell Banquet to* Prof. TYNDALL, *Delmonico's, New York, 1873.*)

WESTON ELECTRICAL INSTRUMENT CO.

NEWARK, N. J.

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ARGUMENT

THIS monograph is prepared as evidence of our belief in the new movement to make education more practical. The Weston Electrical Instrument Company is convinced that the public high school instructors desire to use pedagogic material drawn from real life and prefer to perform laboratory experiments which teach the fundamentals of science as far as possible with commercial equipment, such as the student will later use or see used, and with which he will later be expected to be familiar.

Assured that teachers want to know what technical men in the industries believe to be fundamental, we have prepared brief suggestions relating to the preparation of a course in electrical measurements. Representatives of our house have been observing the work of schools for several years. In issuing this monograph, we have consulted authorities on pedagogics. We have also received the advice of school men and have then printed such matter as appealed to our judgment.

Some of the suggestions offered may be beyond the present scope of high school physics, although extremely elementary from our standpoint.

Since this is neither presented as a text book, nor offered as a complete outline of a course of study, but merely contains material offered for consideration, it is probable that, as this movement progresses, exercises which are at present too advanced may later be acceptable and even necessary.

Exercises credited to authors of text books have in some instances been abbreviated but not altered in detail, even though in our judgment and in the judgment of members of the Joint Committee changes could well be made. We have, however, appended our opinions when we differed considerably with the author, or believed suggestions were appropriate.

We hereby express our thanks to the authors and publishers who permitted us to quote from their works.

We wish to acknowledge our indebtedness to the members of the Joint Committee on Physics who have advised us in both the general plan of the monograph and in the selection and arrangement of the material. All of our suggestions which were adjudged by the committee members to be impracticable under existing conditions pertaining to schools have been eliminated. However, every effort has been made to make this monograph represent the judgment of our Staff, rather than that of the educators consulted.

WESTON ELECTRICAL INSTRUMENT COMPANY.

THE EXTENSIVE USE OF ELECTRICAL ENERGY IN NUMEROUS INDUSTRIES

In re-outlining the course of study in high schools, due consideration should be given to the fact that changes in the relative importance of certain industries have recently taken place, and that these changes affect both the home and the civic life of our people in various communities.

The new census gives figures to support the statement that electrical industries are economically more important than the chemical industries in point of the number of wage-earners employed and in the value of the product manufactured each year.

It is estimated that ten billion dollars are now invested in electrical industries. About one-fourth of this represents the capital invested in power developments of a semi-public nature.

The educational significance of these facts is two-fold:

First. In emphasizing that *more attention must be given by instructors to the industrial applications of electricity, and to physics generally.*

Second. In the direct answer which they give to the question as to what constitutes *practical* ideas from the business man's point of view. We will elaborate this point. The greater portion of this tremendous investment is dependent upon the maintenance of circuits having a pressure of 110 volts or over. Accordingly the first things that students should learn are the facts concerning these circuits. For developing means of teaching these and other facts the country is dependent upon its educators. It is from teachers only that the student may obtain comprehensive ideas relating to the materials, arrangement and methods of distribution of electrical circuits. Just as the water and gas mains, with their innumerable outlets and ramifications, supply a city with two necessities, the electrical conductors give us access to an agent—a source of energy—which has become more necessary to us than gas, and in frequent instances is

almost as indispensable as water. And this agent, this source of energy, is an electric *current.*

It seems logical and proper, therefore, that a course in elementary electrical measurements should begin with the consideration of the subject from the standpoint of current.

CURRENT

The following exercise, published in the Manual of Fuller and Brownlee,* Experiment 77, is here given in part as an illustration of a method of teaching current distribution.

EXPERIMENT I

RESISTANCE AND CURRENT IN A DIVIDED CIRCUIT

Object. To compare (*a*) the currents in the branches of a divided circuit with the resistance of those branches; (*b*) the total resistance with the resistance of the branches.

Apparatus. Lamp board like that shown in Fig. 1; 32-candle-power lamps to fill board; 3 ammeters; voltmeter, with connecting wires; connections to 110 volts D.C. circuit.

Experimental. Proper connections for a circuit of two branches, like that shown in Fig. 1, are to be made. The resistance in each branch of the circuit consists of an equal number of similar incandescent lamps, connected in parallel. The ammeters are so connected that the total current through both branches can be read and also the individual current in each branch. The terminals of a voltmeter, which is not shown, are to be connected to the terminals of any portion of the circuit whose resistance is desired.

All the lamps on both sides are to be turned on and reading of each ammeter recorded. The voltmeter is then connected in succession to the terminals of each branch circuit and to the terminals of the combined circuit and the readings obtained recorded in tabular form.

* Published by Allyn & Bacon, Boston.

All the lamps but one on one branch are then turned out, leaving all the lamps in the other branch of the circuit burning. Readings of the voltmeter and ammeters are taken and recorded as before. Make the following additional combinations in the two branches and record the results: 2 lamps and 3 lamps; 2 lamps and 4 lamps; 2 lamps and 5 lamps.

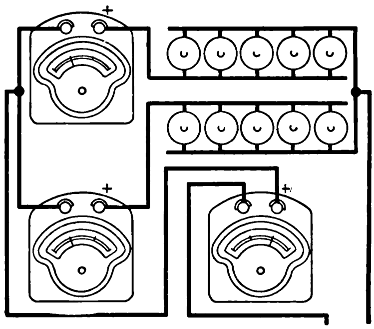


FIG. 1.—Lamp Board, Ammeters and Connections.

Instruments used are Model 280 Weston Ammeters, Range 10 Amperes.

A simple diagram of connections should be made, and a brief description of the method of making the tests should be given. From the readings of the instruments the resistance of each branch and the resistance of the entire circuit should be calculated for each case by the application of Ohm's Law.

Discussion. Does increasing the number of lamps in parallel in a circuit increase or decrease the resistance of the circuit?

EXPERIMENT II

THE DISTRIBUTION OF CURRENT, VOLTAGE AND POWER IN A MODEL LIGHTING CIRCUIT. TWO-WIRE SYSTEM.*

Apparatus. Model lighting circuit; 110-volt supply; ammeter; two voltmeters; rule; fuses.

Method. The line wires, Fig. 2, are composed of a high-resistance wire. The taps from the line wires (except at Group *V*) are of heavy copper wire. This furnishes a model lighting circuit, which has a measureable loss in voltage and power in the line wires, as would be the case for an actual incandescent

* From The Loose Leaf Manual, Timbie's Electrical Measurements. Published by John Wiley & Sons, Inc.

lighting circuit. The openings, 1, 2, 3, etc., are made so that an ammeter can easily be inserted to measure the current in all parts of the system.

Get directions from an instructor regarding the ohms per mil-foot of the line wire and the number of lamps to be used in the line, and their arrangement. Record all readings of current, voltage, etc., on a single outline diagram of the line, similar to Fig. 2.

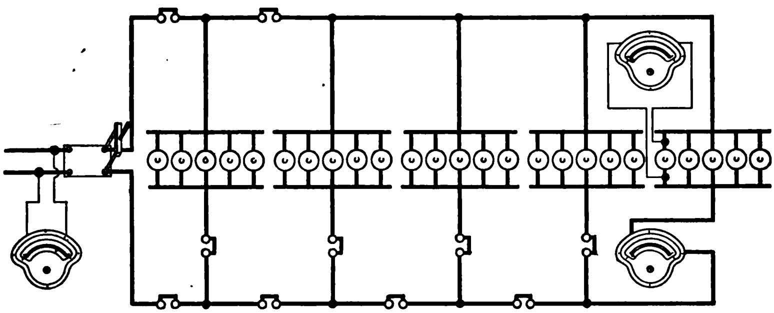


Diagram of the Model of a Lighting Circuit, used in Pratt Institute, Brooklyn, N. Y.

Fig. 2.—The Instruments Shown are Weston Model 267, Voltmeters and Ammeters.

Data and Results. The switch at the end of the line is to be regarded as the source of power. Measure the voltage at this switch and the current in each section of the line *at this voltage.*

Measure with a micrometer caliper the size of the line wire, also with a rule the distance from the switch to the first group of lamps, and the distance from each group to the next succeeding group. (Measure in each case to the point on the mains at which the short leads from the lamps are attached. The resistance of the short copper leads to the lamps may be neglected.)

From its length and mil-foot resistance, compute the resistance of each section of the line. Compute the " drop " over each section, and the voltage at each group of lamps. Check your computed voltage by comparison with voltmeter readings taken across the lamps. *As the supply voltage may fluctuate, one voltmeter should be kept con-*

nected across the supply switch, and the voltage at the lamps should be read from a second voltmeter when voltage at the switch is at the proper value.

From your data determine also:

1. The watts delivered at the power switch.
2. The watts expended in each section of the feed wires.
3. The watts expended in each group of lamps.
4. The total watts supplied to the lamps, and the total line loss.
5. The "efficiency" of the line—i.e., the per cent of the total power supplied which is delivered to the lamps.
6. The resistance of each group of lamps.
7. The average hot resistance of a single lamp.

Show all computations in your report.

From your data determine also:

1. The watts delivered at the binding post terminals.
2. The watts expended in each section of the feed wire.
3. The watts expended in each group of lamps.
4. The total watts supplied to the lamps and the total line loss.
5. The "efficiency" of the line, i.e., the percentage of the total power supplied which is delivered to the lamps.
6. The resistance of each group of lamps, and the average hot resistance of each lamp.

If conditions permit, we would suggest that a teacher would better have small groups of students use a part of the actual lighting circuit in the school, in place of a model, and follow the directions given in the experiments as far as possible.

This plan is suggested by the letter on page 26 of our Monograph B–1, written by Mr. C. W. Parmenter, Head Master of the Mechanics Arts High School, Boston. The plan is also used by Prof. H. H. Higbie of the Wentworth Institute, Boston, Mass.

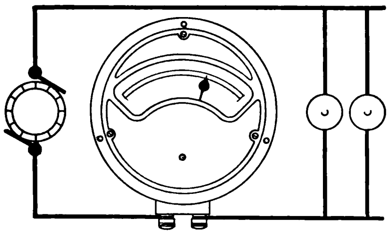


FIG. 3.—Connection for Ammeter with Self-contained Shunt.

Instrument shown is a Weston Model 24.

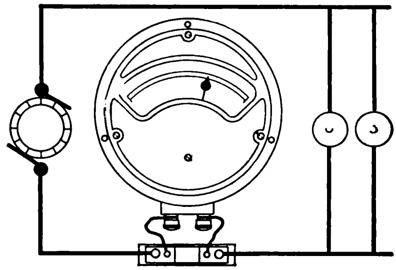


FIG. 4.—Connection for Ammeter with Detachable Shunt.

Instrument shown is a Weston Model 24.

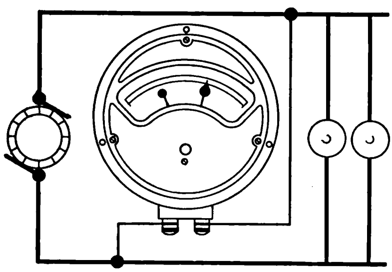


FIG. 5.—Connection for Voltmeter.

Instrument shown is a Weston Model 24.

CONNECTIONS FOR VOLTMETERS AND AMMETERS

The student's attention should be called to the fact that an ammeter should always be connected in series with the line, whereas a voltmeter should be connected across the line. See Figures 3, 4 and 5.

EXPERIMENT III

THE FALL OF POTENTIAL ALONG A CONDUCTOR

The nature of a divided circuit and the current in it may have been called the primary idea in the preceding experiments, but they served as well as means of discussing the theory that it is *pressure* which actually forces the current through.

Schools have for a long time given an exercise showing the "Fall of Potential along a Conductor," and it merely remains for the teacher to give this exercise a more practical atmosphere to have it continue to be one of the strongest on the list.*

* See Experiment No. 29, Laboratory Manual in Physics. Wauchope, Scott, Foresman & Co., New York and Chicago.

Apparatus Required. Weston ammeter, range 3 amperes; Weston voltmeter, range 3 volts; 1 meter slide wire bridge; storage cell or 2 constant primary cells in series; No. 18 (B. & S. gauge) 40-mil Weston alloy wire; No. 24 (B. & S. gauge) 20 mil-Weston alloy wire.

A length of 40-mil alloy wire is stretched over the meter rod and securely clamped. The resistance of 40-mil alloy wire is approximately 0.50 ohm per meter.

One storage cell, with the ammeter in series, is connected with the stretched wire, an extra piece about ½ meter long is included in the circuit and its length is regulated until the current flowing is 3.00 amperes. See Fig. 6.

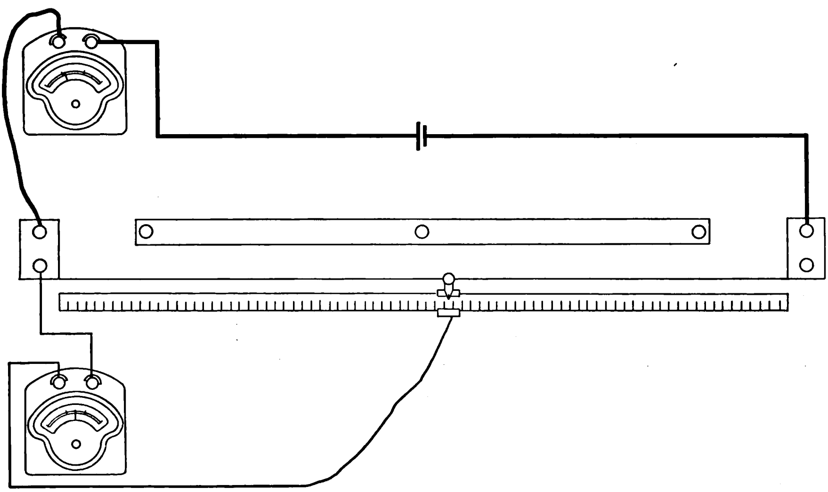


FIG. 6.—Ammeter is a Weston Model 280 Range 3 Amperes. Voltmeter is a Model 280 Range 3 Volts, Zero in Center.

The 3-volt range of the voltmeter is also connected as shown and primarily the drop over the entire length of wire is found The resistance of 1 meter of wire is then determined by the formula $R=\frac{E}{I}$.

It must be borne in mind, however, that this is not a " zero " method, and theoretically, at least, is not correct. That is to say, since current is necessarily flowing through the voltmeter

when in use, the instrument therefore forms part of a divided circuit by shunting the resistance wire.

If an improperly constructed voltmeter of low resistance is employed, its introduction will affect the indications of the ammeter by materially reducing the total resistance of the circuit, and its own indications will be erratic and disproportionate when different lengths of the resistance wire are being tested.

Weston voltmeters have sufficiently high resistances to prevent the irregularities referred to, but nevertheless the best method for determining the total resistance of the wire is to ascertain the drop over definite lengths of the wire, such for instance as 10 centimeters, tabulate the results, obtain a mean value and determine the total resistance by direct proportion.

When sufficient data have been secured relating to the 40-mil wire, a piece of 20-mil is substituted, and the test repeated. A current of about 1.00 ampere may be used. The resistance of 20-mil alloy is about 2 ohms per meter.

A length of copper wire may also be tested, preferably one having a diameter of 0.020 inch, and the relative resistance of copper and Weston alloy wire determined.

Caution: Weston alloy wire has about 23.5 times the resistance of copper wire, and therefore the experimenter must be cautioned to add enough alloy wire to the circuit to compensate for this difference, before the current is completed through the copper wire.

The fall of potential along a conductor may also be beautifully shown with this apparatus by substituting a wire the resistance of which is not uniform. Such a wire may easily be prepared by scraping or filing a resistance wire at irregular distances while stretched, and by coating it with a little solder here and there, afterwards smoothing with emery paper.

The two voltmeter leads are then held, one in each hand, so as to span a section of the wire, and the deflection is noted and compared with the results obtained with other sections of the same length.

EXPERIMENT IV

THE FALL OF POTENTIAL IN A LAMP BANK *

Question. What is meant by "Fall of Potential"?

Apparatus. Source of 110-volt current; three electric lamps; voltmeter.

Directions. Pass the current through the three lamps connected in series as shown in the diagram. It requires electrical

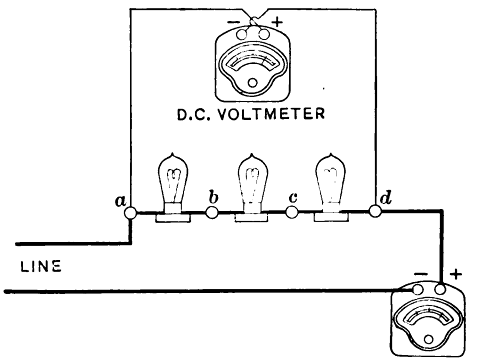


FIG. 7.

Instruments used are a Model 280 Weston Ammeter, Range 3 Amperes, and a Model 280 Weston Voltmeter, Range 120 Volts.

pressure to force the current through the lamps. This pressure is measured by the voltmeter. Connect the terminals of the voltmeter to *a* and *d* to obtain the volts pressure required to drive the current through all three lamps. In like manner find the difference of electrical pressure between *a* and *c* for two lamps, and between *a* and *b* for one lamp.

Results. Volts pressure required for three lamps =
Volts pressure required for two lamps =
Volts pressure required for one lamp =

Discussion. Potential is only another expression for electrical pressure. Difference of potential means difference of electrical

* From "Manual in Physics," by Joseph A. Wauchope.

pressure, and fall of potential means fall of electrical pressure. A voltmeter is used to measure the potential difference between any two points in an electrical circuit, just as pressure gauges are used between any two points of a water pipe. The further away from the pumping station the greater the fall of pressure of the water in pounds per square inch, due to the resistance of the pipes.

So the further the electric current goes in a conductor the greater the fall of potential in volts, due to the electrical resistance of the conductor. The greater the resistance the greater the fall of potential. Do the lamps used in this experiment all have the same amount of resistance? Why do not the lamps give light in this experiment?*

EXPERIMENT V

NUMBER OF WATTS FOR ONE BRITISH THERMAL UNIT PER SECOND

In "Physics," by Mann and Twiss,† the following exercise is suggested, which has long been successfully used in schools to teach that the electrical energy delivered to an incandescent light is transformed into heat energy.

An ordinary 16-candle-power, 110-volt, electric lamp is placed in a jar containing a measured amount of water and a thermometer (Fig. 8). The heat from the lamp warms the water. If the jar contains 2 pounds (1 quart) of water and if a Fahrenheit thermometer is used, the temperature of the water rises about $1\frac{1}{2}°$ F. per minute—i.e., the water is heated at the rate of 3 B.T.U. a minute.

* In the "Physical Laboratory Manual," by Ball, Hauptman and Bateman, issued by the Cooper Union Supply Store, New York, a different method is given, which consists in employing a lamp bank, a gold-leaf electroscope, and a Weston voltmeter.

They call attention to the fact that the leaves of the electroscope will diverge less and less as the knob of the electroscope is connected at the points of decreasing potential, and then add:

"Now use a Weston voltmeter in place of the electroscope and note the readings of the voltmeter for the same points. Note how much more accurately the potential difference can be estimated by means of the voltmeter than by means of the electroscope."

† Scott, Foresman & Co., Publishers, New York and Chicago.

A voltmeter and an ammeter measure the electric power supplied to the lamp. If the voltmeter reads 110 volts, and the ammeter reads $\frac{1}{2}$ ampere, the power supplied is 110 (volts) $\times \frac{1}{2}$ (ampere) = 55 watts. Hence, roughly, 55 watts = 3 B.T.U. per minute; or 1100 watts = 1 B.T.U. per second.

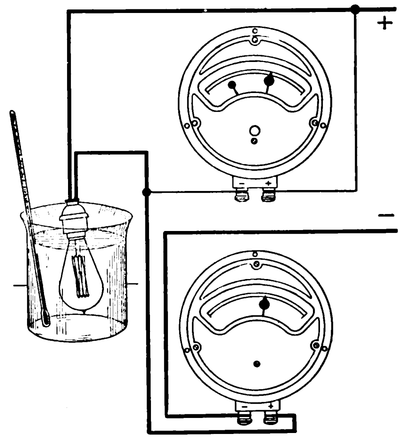


Fig. 8.

Instruments used are a Weston Model 24 Voltmeter and Ammeter.

The first determination of this relation was made more accurately by the same Joule who made the first determination of the relation between the B.T.U. and the foot-pound. The apparatus (Fig. 9) does not differ in principle from that used by Joule. A coil of platinum wire is placed in a jar containing a measured quantity of water and a thermometer. A voltmeter and an ammeter, arranged as shown in Fig. 8, measure the number of watts of electric power used in heating the coil. The number of B.T.U. given up by the coil to the water in a certain time is obtained by multiplying the number of pounds of water in the jar by the number of degrees F. rise in temperature.

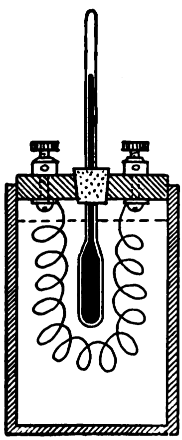


Fig. 9.

Joule's experiments have been repeated many times by many other scientists, using different current strengths and different kinds of coils. The results of all of these experiments show that there is a constant ratio between the heat unit and the unit of electric power; and they give the accurate value of this ratio as

1055 watts = 1 B.T.U. per second.

4.2 watts = 1 gram-calorie per second.

The above exercise, as described, deals merely with the rela-

tion that the power units (watts and B.T.U. per second) bear to each other.

EXPERIMENT VI

HEATING EFFECT OF AN ELECTRIC CURRENT

The following directions, reprinted from "Laboratory Exercises in Physics," by Fuller and Brownlee, seem to be more practical than the preceding one.*

Object. To measure the number of calories of heat furnished by an incandescent lamp and to calculate the cost.

Apparatus: Calorimeter; thermometer; 16-candle-power incandescent lamp; porcelain keyless socket; voltmeter; ammeter; source of 110-volt current; graduate, or balance and weights; flexible insulated wire for connections; watch or clock with second hand.

By allowing a lamp to heat a known weight of water for a measured time, we may find the calories per second furnished by the lamp. If we know the current and voltage of the lamp, we may estimate the heat liberated per kilowatt-hour. Although *all the heat* liberated by the lamp will not be measured in this experiment, yet the efficiency of the lamp as a heater, as used here, compares favorably with regular heating apparatus.

Experimental. A porcelain keyless socket is connected to a 110-volt line with an ammeter between the socket and the 110-volt terminals (Fig. 10). A voltmeter is connected across the terminals of the socket. A lamp is then screwed into the socket and the switch closed in the circuit to make sure that the connections are correct and that the instruments read in the proper direction. The lamp is then turned off till needed.

Into a nickel-plated brass calorimeter is placed 250 grams of water at a temperature six or seven degrees below room temperature.

This is stirred thoroughly with a thermometer and the temperature noted; immediately the current is turned on through the lamp, which is inserted in the calorimeter, the exact time in minutes and seconds being noted.

* See also Experiment 92 in "Experimental Physics," by Smith, Tower and Turton. Ginn & Co.

The time and the temperature of the water are recorded in the tabular form near the top of the left-hand page, the voltmeter and ammeter also being noted and recorded. The lamp should be immersed until the tip rests on the bottom of the calorimeter, and the thermometer should stand in the calorimeter beside the lamp. For the next five minutes the lamp burns inverted in the water. By moving the lamp up and down in the water, never raising it more than a quarter of an inch from the bottom, the water can be kept stirred and so of equal temperature throughout.

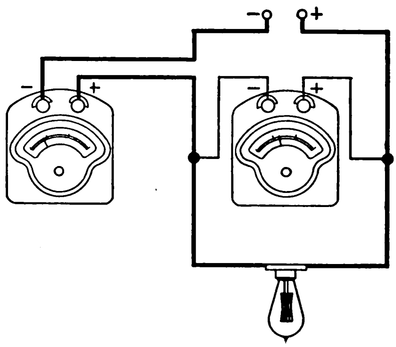


Fig. 10.

Instruments used are a Model 280 Weston Ammeter, Range 3 Amperes, and a Model 280 Weston Voltmeter, Range 120 Volts.

The calorimeter should not be handled during the experiment. The voltmeter and ammeter should be frequently observed, and if there is any variation, the average reading for the whole time should be the one recorded and used.

When the lamp has been in the water exactly five minutes, take it out promptly, stir the water vigorously with the thermometer, and read and record the temperature.

Using fresh quantities of water, repeat the test twice. The water equivalent of the calorimeter should be obtained from the instructor.

Make a sectional drawing of the calorimeter with lamp and thermometer in place and with the connections of the instrument shown.

A brief description of the method of the experiment should accompany the drawing.

From the weight of the water, with the water equivalent of the calorimeter added, and the change of temperature, the number of calories furnished in five minutes can be calculated. The number of watt-seconds is found by multiplying volts, amperes, and seconds together. From these two results calculate the

calories per watt-second and per kilowatt-hour. As the time and the weight of water are the same in all three tests, the averages of temperature changes, volts, and amperes will be used in the calculation. The problem called for in the conclusion should be worked out in the note-book, using the local rate for electricity.

CALCULATED RESULTS

Corrected weight of water (water+water equivalent of calorimeter). .	g.
Average temperature change in five minutes.	c.
Calories furnished in five minutes.	cal.
Calories furnished per second.	cal.
Watt-seconds of energy used in five minutes.	w. s.
Calories per watt-second.	
Calories per kilowatt-hour.	
Cost of current per kilowatt-hour.	c.

Discussion. Explain any way in which heat generated by the lamp may escape without being measured in this experiment.

Conclusion. At the price of . . . ¢ per kilowatt-hour, the cost of raising 4 liters of water from 15 to 100° C. will be . . . ¢ if an electric heater of the same efficiency as the lamp is employed.

POWER

A series of exercises designed to emphasize the difference between work and power as measured in electrical units (e.g., watt-hour and kilowatt) is commercially of primary importance.

In " A High School Course in Physics," by Gorton,* will be found the following terse and lucid definition:

" POWER OF AN ELECTRIC CURRENT. Since *power* refers to the rate at which work is done or energy expended, it may be found by simply dividing the total energy expended by the time. In an electric circuit, therefore, the power is measured by the product of the potential difference and the current strength; or, *Power* (watts) = volts × amperes."

* D. Appleton & Company, Publishers. New York and Chicago.

EXPERIMENT VII

EFFICIENCY TEST OF AN ELECTRIC MOTOR

There is a rapid increase in the number of school laboratories which have a small electric motor. These motors are usually of recent design, and of ½ horse-power or over in rating.

The student who uses motors of this type is usually impressed by the fact that he is working with real commerical quantities of energy and with actual life-size machines.

A determination of the brake horse-power and efficiency of such a motor is considered an essential part of the laboratory course in many of our high schools. Such a test is very well described in "Physics," by Mann and Twiss, as follows:

"As with simple machines, water motors, and steam engines, the most important thing about electric machines is the efficiency.

"Suppose that we have bought a 110-volt motor that is built to develop two horse-power, and we wish to test its power and efficiency in order to see whether it does what is claimed for it. The voltmeter V, whose terminals are attached to those of the motor (Fig. 11), measures the $P\,D$ at the motor. It should read 110 volts. The ammeter A, placed in the power circuit in series with the machine, measures the number of amperes flowing through the motor. Suppose it reads 16 amperes. Then the power supplied to the motor (power in) is

$$110\text{ (volts)} \times 16\text{ (amperes)} = 1760\text{ watts.}$$

"A brake is applied to the axle of the motor and the readings made.

"Let us suppose these readings to be as follows:

"Circumference of brake wheel, 2 feet; revolutions per minute, 360; pull on brake, 82.5 pounds. Then the power obtained from the motor is:

$$82.5\text{(lbs.)} \times 2\text{(ft.)} \times 360\text{(r.p.m.)} = 59{,}400\text{ ft.-lbs. per min.}$$

"Dividing this by 33,000 ft.-lbs. per min. to reduce it to horse-power, we get 1.8 horse-power.

"So 1760 watts of electric power was supplied to the motor to make it do work at the rate of 1.8 horse-power. This result enables us to compare the efficiency of this motor with that of others; but it does not state what the real efficiency of this motor is, because the power in is expressed in watts, and the power out is expressed in horse-power." *

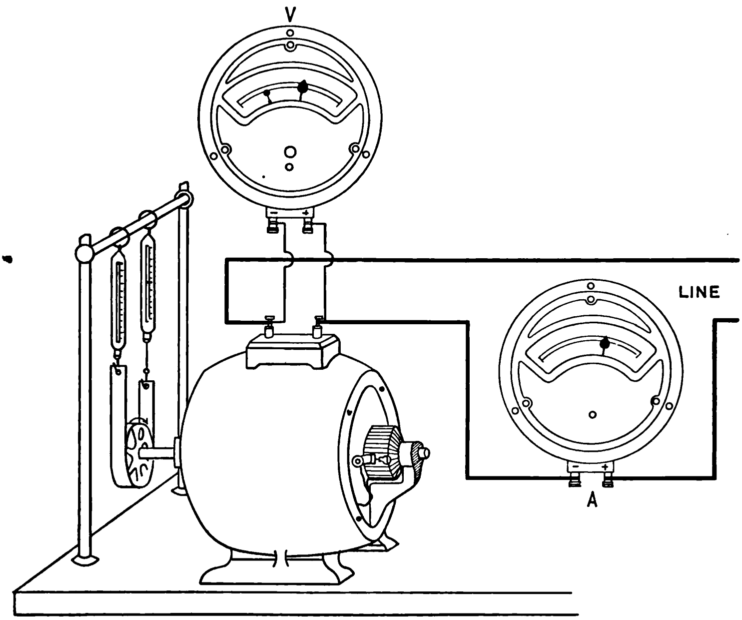


FIG. 11.

Instruments used are a Model 24 Weston Ammeter and Voltmeter. Ranges 25 Amperes and 125 Volts.

RESISTANCE

The most accessible means for measuring quantities with commercial accuracy are the ones most frequently ignored. In the measurement of resistance it is perhaps true that instructors neglect the voltmeter-ammeter method because it seems so obvious. Certainly no quicker method could be selected than

* See also Experiment 37, Wauchope's Manual in Physics. Scott, Foresman & Co. New York and Chicago.

that of placing an ammeter in series, and then connecting a voltmeter across the terminals of the conductor to be tested. Nothing else is necessary except perhaps a rheostat to regulate the amount of current.

Every student knows enough of algebra and of Ohm's law to solve for the resistance when he has taken such measurements. The student who is thus early asked to test the resistance of each phase of an induction motor, the fields of a direct-current motor, the ballast coils in an arc lamp, or any other electrical device, starts with a fair appreciation of what ordinary commercial measurements of resistance are like.

The following experiment fully describes the advantages and limitations of this method:

EXPERIMENT VIII

THE DETERMINATION OF LOW RESISTANCES BY THE AMMETER AND VOLTMETER METHOD

Apparatus Required: Weston ammeter; Weston millivoltmeter, 500 millivolt range; Weston voltmeter, 3 and 15 volts; unknown low resistance; storage battery, 3 cells, Weston alloy or carbon rheostat.

This method is identical in principle with the one by which the fall of potential along a conductor is determined. Commercially, it is constantly used for testing the resistances of busbars, dynamo armatures, shunts, etc.

A Weston ammeter, preferably with a detachable shunt having a standard drop, is connected in series with the resistance material to be measured, a rheostat, and a source of steady current.

Current is regulated until a suitable ammeter deflection is obtained.

If the resistance of the material to be tested cannot be determined approximately by calculation, a voltmeter should first be connected across its extremes *a* and *b* (see Fig. 12) and a preliminary test made to learn whether the potential between these points is too great to permit the use of a millivoltmeter. If this is not the case, the millivoltmeter is substituted, its deflec-

tion noted, and the resistance between a and b is found by the formula

$$X=\frac{E}{I},$$

I being the current and E the e.m.f. indicated by the millivoltmeter.

Strictly, the value obtained is not that of the resistance material only, but of the combined resistance of the material and the millivoltmeter in parallel.

To determine the resistance accurately, a more refined method must be used, as follows:

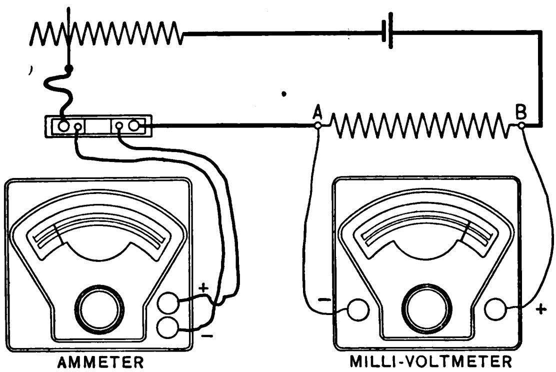


FIG. 12.

Weston Model 1, Instruments.

After the "drop" and current have been ascertained as given above, the leads of the millivoltmeter are disconnected and the resistance of the instrument (if unknown) is measured by a bridge. Then the true resistance of the material between the potential points is:

$$X=\frac{Er}{Ir-E}.$$

r = Resistance of the millivoltmeter.

Examples:

Let $0=1.4$ amperes; $E=0.056$ volt, and $r=2$ ohms; then

$$X=\frac{0.056\times 2}{(1.4\times 2)-0.056}=0.040817 \text{ ohm}.$$

If the first method were used, $X=\frac{E}{I}$ would give $X=\frac{0.056}{1.4}=0.04$, or an error of about 2 per cent.

If, however, the current were 450 amperes and the drop 0.054 volt, by $\frac{E}{I}$ we would have $\frac{0.054}{450}=0.00012$ ohm, and by the second formula $X=\frac{2\times 0.054}{(450\times 2)-0.054}=0.0001200072$,

and the difference in the results would be negligibly small. Hence, when very low resistances are being measured and large currents are used, the simpler method is preferable.

Another variation of this method, which is useful for measuring armature resistance, etc., results from the use of a single millivoltmeter, and a known low resistor approximately equal to the unknown resistance, in place of the shunt. Then by first connecting the millivoltmeter across the resistor, the current through the circuit may be computed by Ohm's law. Next, by placing the instrument terminals across the unknown resistance, the fall of potential through it and also its resistance may be then determined. With steady current, this method is as accurate as the first one, but since it is assumed that the conditions do not change between tests, it cannot be relied upon with fluctuating current.

INSULATION

An ideal condition of affairs would be to have a perfect conductor of electricity protected by a perfect insulator. We would then always secure 100 per cent efficiency, irrespective of the length of cross-section of our conductor. But unfortunately we have neither, since all conductors have resistance and all insulators are imperfect conductors. The result is that there is always a current discharge on a line. This discharge or "leakage" is increased by the use of poor or worn insulating material and by dampness.

In all electric light and power stations, leakage is regarded as waste, involving a direct financial loss. Therefore, it is of great importance to be able to "keep up the line insulation" and to understand how to locate leaks or "grounds."

EXPERIMENT IX

THE DETERMINATION OF HIGH RESISTANCES BY THE VOLTMETER DEFLECTION METHOD

Apparatus Required: Weston direct-current voltmeter, 150-volt range; high unknown resistance; direct-current line voltage, 100 to 120 volts.

On a direct line, in order to successfully determine insulation resistance, it is necessary to use a Weston permanent magnet movable-coil type of high-resistance voltmeter, with a uniformly divided scale. The resistance of the instrument should be known.

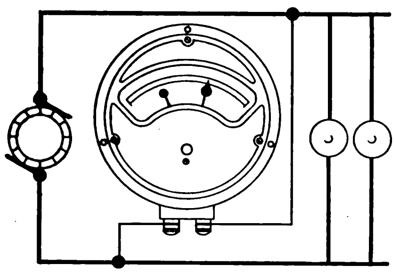


FIG. 13.

Weston Model 24 Voltmeter, Range 150 Volts.

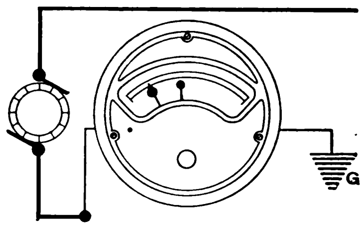


FIG. 14.

Weston Model 24 Switchboard Voltmeter, Range 150 Volts.

The normal voltage of the line is then found by connecting the voltmeter across the line, as shown in Fig. 13, and the deflection noted.

One binding post of the instrument is then grounded by connecting it with any convenient water, gas or steam pipe, and the other binding post connected directly with one of the generator terminals. The other generator terminal is connected with the line to be tested and the resultant deflection also noted. See Fig. 14.

The resistance of the line (in ohms) is then found by the formula:

$$X = \frac{S \times R}{S'} - R.$$

S = First deflection in scale divisions;
S' = Second deflection in scale divisions;
R = Instrument resistance.

Example:

$$S = 120; \qquad S' = 20; \qquad R = 15000;$$

$$X = \frac{120 \times 15000}{20} - 15000;$$

$$X = 75000.$$

The insulation resistance of a line or cable may readily be determined in this manner if it is not too high.

Sometimes, when the insulation is very poor, a fine class-room illustration can be made by grounding the line through an ammeter in series with an incandescent lamp, as shown in Fig. 15.

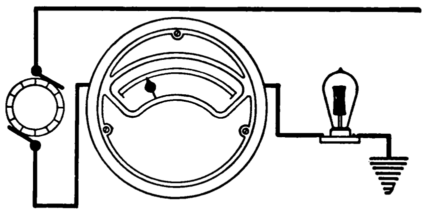


FIG. 15.
Weston Model 24 Switchboard Ammeter, Range 5 Amperes.

EXPERIMENT X

THE WHEATSTONE BRIDGE

The Wheatstone bridge remains the time-honored instrument for the highly accurate determination of resistance. In commercial testing laboratories, it is regularly used for routine and special work demanding greater precision than can readily be obtained by more rapid methods. Its use is also common for measurements in which the large currents or voltages required by other methods are either unobtainable or objectionable. As an illustration, reference might be made to its use in telegraph and telephone tests for faults and grounds. The Wheatstone bridge is operated by specially trained workers, and for educational purposes it should not be classed with voltmeters, ammeters, and wattmeters as an instrument with which every high-school graduate should be familiar.

Many teachers question the wisdom of attempting to teach beginners the principle and operation of this instrument, as much because of the indifferent success which so frequently results as because of its special character. This discussion is intended for those teachers who feel that they must attempt its use. The slide-wire form is here suggested, not only because it is already in common use, but also because it lends itself to a close correlation between the "Fall of Potential" exercises which should precede it.

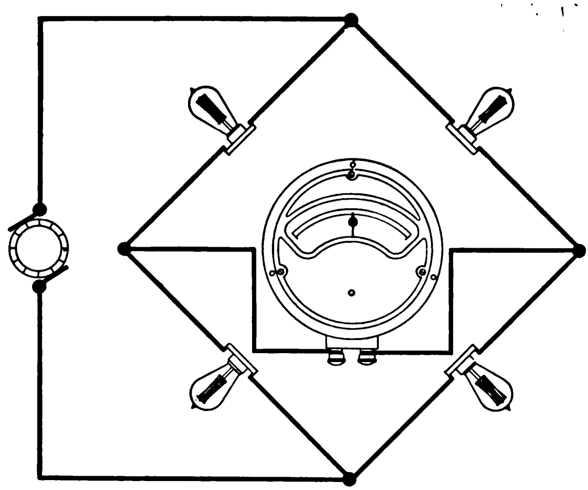


Fig. 16.

The Instrument is a Weston Model 24 Zero Center Ammeter.

Apparatus Required: Slide wire bridge; Weston student galvanometer; Weston ammeter; resistance box; resistance wire; coil of unknown resistance; one or two cells; incandescent lamps.

If four incandescent lamps are arranged in multiple series, as shown in Fig. 16, and connected in the line, they will serve excellently to demonstrate the principle of the parallelogram of forces, as exemplified by the Wheatstone bridge. Even if the rest of the exercise is omitted, this part should be given as a classroom demonstration. The instrument should preferably be a zero center ammeter.

Suitable questions would be as follows:

If an ammeter is connected (as shown), what will happen? Will it indicate, and if not, why not?

If one of the lamps is removed, what will be the result?

If a lamp of different size (resistance) is substituted, will it make any difference?

If, instead of the lamps, a parallelogram of resistance wire is constructed so that the four sides have the same resistance, and a battery and galvanometer are connected, as shown in Fig. 17, the current will split where A and B unite, pass through A and X and also through B and R, reuniting where R and X join. The four "arms" of the bridge being alike, no current will flow through the galvanometer when connected as shown. In other words, the potential at the junction of AX and BR will be the same. The battery and galvanometer may then be interchanged without affecting the balance.

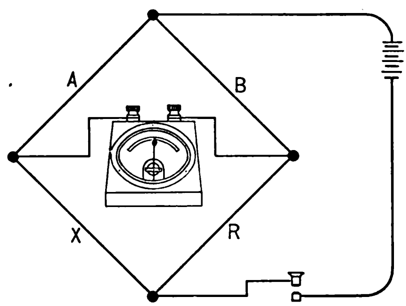


Fig. 17.

The Instrument is a Model 375 Weston Galvanometer.

To construct a practical bridge, it is only necessary to substitute for A, B, X, and R conductors of large area and negligible resistance with suitable gaps for the insertion of resistance coils and the material to be measured. See Fig. 18. If then, A and B are each 100 ohms and R is also 100 ohms, a balance is secured by adjusting X, and when no current flows through the galvanometer the resistance of X will be 100 ohms. If the resistance of X is to be determined, R is made adjustable and is varied until it equals X. The resistance of R and X, if equal to each other, may differ greatly from A and B, and an equilibrium be established, provided A and B equal each other. Finally A, B, R, and X may all differ in resistance and a balance be secured, provided a proportionality exists in their respective resistances—for instance, when

$$A=10, \quad B=100, \quad X=35 \quad \text{and} \quad R=350.$$

These conditions exist when an uneven bridge or ratio is used in making measurements.

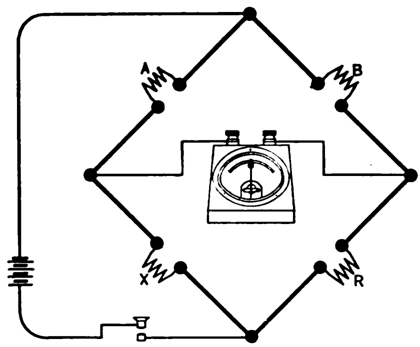


FIG. 18.

Instrument Shown is a Model 375 Weston Galvanometer.

EXPERIMENT XI

THE SLIDE-WIRE BRIDGE

In the slide-wire form of bridge *A* and *B* consist of a single wire of a uniform resistance. Contact may be made at any point on this wire and a scale is provided to determine the posi-

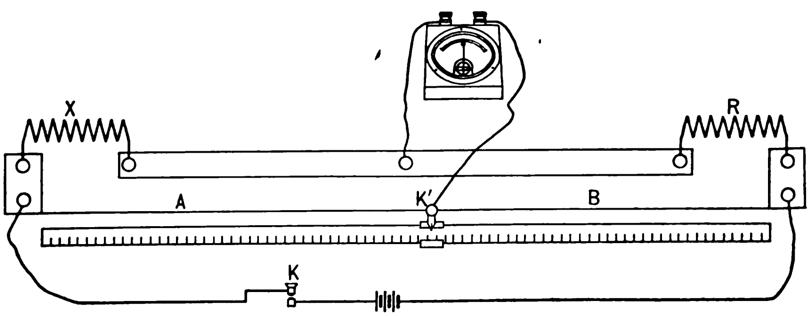


FIG. 19.

The Instrument is a Model 375 Weston Galvanometer.

tion of contact. See Fig. 19. The galvanometer is preferably connected as shown; an unknown resistance is inserted at *X* and a box of coils at *R*.

Contact keys k and k' are used to close the circuits through the battery and galvanometer.

The slide-wire contact is at first placed centrally, and an approximate balance secured by varying R. A place is then found on the slide wire where perfect balance is secured.

Since the scale is divided into a thousand parts, the resistance of X can be closely determined by simple proportion.

EXPERIMENT XII

THE EFFECT OF TEMPERATURE ON THE RESISTANCE OF A LAMP FILAMENT *

Apparatus: 110-volt direct current; series lamp resistance or any suitable adjustable resistance; switch with 6-ampere fuses; ammeter; voltmeter; lamps to be tested. (These should be of several types.)

The difference between the resistance of an incandescent lamp filament when the switch to power is first closed and the resistance of the same filament an instant later when the filament has been raised to its normal operating temperature, is a matter of considerable commercial importance. With the old type carbon filaments, where the temperature effect is to give a smaller initial current, the phenomenon could be safely allowed to adjust itself. With the newer metallic filament lamps in which the first rush of current may be much greater than the normal operating current, some protection to the line, when the power switch is first closed, is frequently necessary where large groups of lamps are being supplied. That the character and extent of this temperature effect vary with various types of lamp filaments will be apparent from the following study.

Method. Connect your apparatus with the 110-volt circuit as shown in the diagram, using first a carbon filament test lamp. (The voltmeter is here connected around the ammeter so that the latter may read the true current through the lamp.) Put a fuse in the line to protect the ammeter. See Fig. 20.

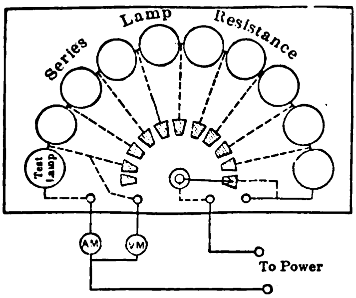
* From "The Loose Leaf Laboratory Manual," Timbie's Electrical Measurements, published by John Wiley & Sons, Inc.

Data and Results. Take readings of both the ammeter and voltmeter with all the lamps in the lamp board in series with the test lamp. Then cut out one lamp at a time, and take readings of the voltmeter and the ammeter for each step, until the last reading is for the test lamp alone. *The ammeter and the voltmeter should be read simultaneously.*

Compute the resistance of the test lamp for each current.

You have no actual measurement of temperature here, but as the current increases the temperature of course rises—very perceptibly for the last two or three readings.

Plot a curve from your data, using the resistances of the lamp as ordinates, the current as abscissae.



EFFECT OF TEMPERATURE ON THE RESISTANCE OF AN INCANDESCENT LAMP

FIG. 20.

What conclusion may be drawn regarding the effect of increase of temperature on the resistance of the filament?

Test in the same way lamps having a treated carbon filament and lamps having a metal filament as in the tantalum and tungsten lamps. Plot curves for each and compare the filaments as to their change in resistance with rise in temperature.

Addenda. Connect the voltmeter across the test lamp only, and note the ammeter reading. Compare this with the ammeter reading taken with the voltmeter connected across both the lamp and ammeter. Which ammeter reading gives the true current through the lamp, and why? Which voltmeter reading gives the true voltage across the lamp, and why? When would it be best to connect the voltmeter across both the ammeter and test piece? When across the test piece only?

Give detailed reasons for your answer. (See Timbie's "Elements of Electricity," p. 413.)*

PROBLEMS: 1. Measure on a Wheatstone bridge the resistance of the tungsten filament lamp at room temperature (20° C). Using the tempera-

* Published by John Wiley & Sons, Inc., New York.

ture coefficient of tungsten as .0051, and the resistance found for the lamp in the above experiment when on its rated voltage, compute the temperature of the filament when used on its rated voltage.

2. In an experiment like the above the voltmeter was connected across the test lamp only. If the resistance of the voltmeter is 16,500 ohms, the voltmeter reading is 110 volts, and the ammeter reading is .285 amp., what is the true current through the lamp filament?

THE WESTON DIRECT-CURRENT AMMETER

For pedagogic purposes the Weston ammeter with detachable shunts has marked advantages over the instrument with a self-contained shunt. The instructor may call attention to the fact that a "shunt" is really a part of the main conductor carrying the current and that only a small fraction of the total current passes through the movable system of the instrument.

A clear conception of the operation of a Weston ammeter may be obtained by means of a water-main analogy. The water main or trunk *A* through which water is flowing under pressure as in city water mains (Fig. 21), may be fitly compared with the conductor or bus-bar *F* (Fig. 22). The section *B* of reduced diameter corresponds with the shunt *E*, and the small pipes *C* may be compared with the leads *G*. It is obvious that, since the pipes *C* are of smaller dimensions than *B*, less water will flow through them; and, provided that the proportion between *B* and *C* is fixed and constant, the quantity of water flowing through the meter *D* will depend upon the total quantity flowing through *B*, and hence *D* may be calibrated to indicate the total flow of water instead of merely indicating the quantity passing through *C*.

On the same principle the scale of the instrument *H* may be figured to indicate any required amperage; but, although the total current flowing through *F* may be 20,000 amperes or more, the sensitivity of the movement of *H* to current is so great that only about 3/100 ampere is required to produce a full-scale deflection, and under proper conditions no current in excess of this amount will ever pass through *H*. The conductors *G*, together with the movable coil and resistors inside of *H*, are so proportioned that the flow of current through *H* is limited to the proper amount. But, nevertheless, instead of merely indicating the amount of current passing through its movement, *H* may

be calibrated to correctly indicate the total current flowing through *FEF*.

Finally, the quantity of current which will flow through *G*

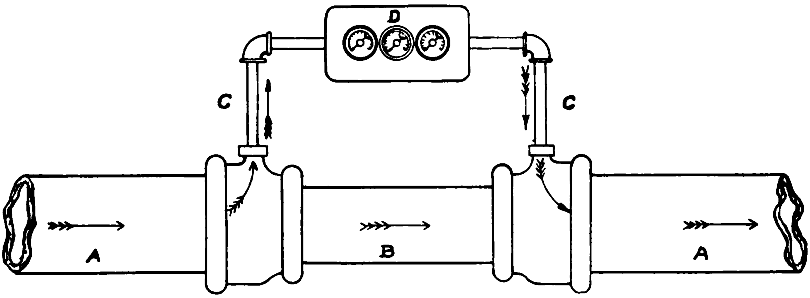


FIG. 21.

will depend upon the resistance of the shunt *E*; therefore, since shunts of different resistances and current capacities may be used in place of *E*, the instrument *H* may be used for an unlimited number of ampere ranges.*

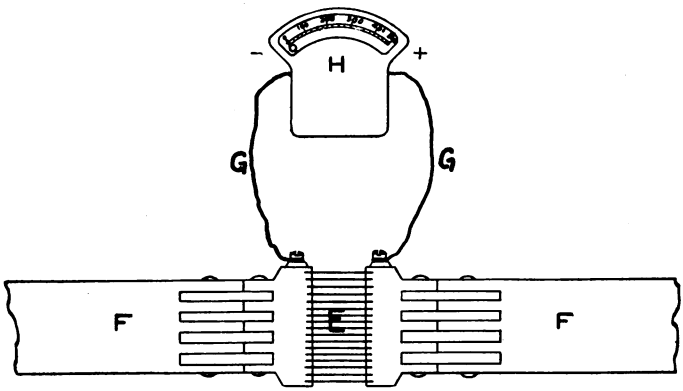


FIG. 22.

Instrument is a Model 11 Weston Illuminated Dial Ammeter.

* A shunt in electrical parlance was formerly defined as a resistor connected in multiple with an indicating instrument carrying the main current to reduce the current flowing through the latter; but, since the introduction of Weston instruments, "shunt" has become the trade name for a constant resistor of special form, having dimensions which will permit its practical use in series with a conductor carrying a current, independent of the current capacity of its indicating instrument.

EXPERIMENT XIII

THE STUDY OF AN AMMETER *

Apparatus: Ammeters of several types.

Ammeters may be divided into two classes: (1) Thermal—in which the movement of the index is secured through the change in length of a wire when heated by the current passed through it. The heat generated, and therefore the change in length, is here proportional to the square of the current; and

(2) Electromagnetic—in which the motion is due to the magnetic field produced when current is sent through the coils or coil of the instrument. Electromagnetic ammeters may be of three types; (*a*) Solenoidal; (*b*) permanent magnet; (*c*) electrodynamometer.

Data and Results. Examine instruments of several of the above types and report upon the following features for each:

1. The type of instrument.
2. The scale: range and graduation. Divisions—uniform or varying width. Why?
3. The construction:
   (*a*) Fixed parts; nature, material, construction and arrangement.
   (*b*) Moving parts; construction, bearings; control by which they are returned to zero; damping.
   (*c*) Shunt.
4. The connections by which the current enters and leaves the instrument. The circuit from binding post to binding post.
5. The resistance of each coil and of each shunt separately. The resistance of the instrument from terminal to terminal.

Explain the construction and arrangement of each essential part by simple diagrams, and show by a simple diagram how the parts are assembled in the complete instrument. Show the

* From "The Loose Leaf Laboratory Manual," Timbie's Electrical Measurements. John Wiley & Sons, Inc.

direction of current through each instrument and explain the reason for the deflection of the moving parts by the current. State in each case whether the instrument is suited for the measurement of direct or alternating current and why.

If the instrument is suited for both direct and alternating current, will the same calibration do for both kinds of power? Explain the reason for your answer.

By means of a millivoltmeter measure the millivolt drop across each instrument on full scale reading and compare this with the computed value. Account for any difference.

Show by diagrams the proper connections of the instrument to a line to measure the current taken by a motor.

PROBLEMS. The full-scale reading of a millivoltmeter is 100 millivolts. The resistance of the moving coil is 5 ohms.

(*a*) What resistance must a shunt be in order to be used with this millivoltmeter to have the scale read amperes?

(*b*) What must the resistance of a shunt be in order that the full-scale reading may indicate 10 amperes?

SUGGESTIONS FOR FURTHER STUDY

If the " drop " of a Weston station shunt of specified ampere capacity is 50 millivolts, what will its resistance be between its potential terminals?

Detach the shunt of a Weston ammeter with removable shunts, and measure the resistance of the instrument by means of a bridge.

NOTE: Minimum current should be used, and the battery key kept depressed to prevent the disturbing effect of currents induced by the motion of the movable coil.

If the drop of a shunt is 50 millivolts, the instrument for which it is intended must necessarily give a full-scale deflection with 50 millivolts. What then will be the amount of current required to give a full-scale deflection when the instrument is used without a shunt?

Explain what the effect would be if the leads from the shunt to the instrument were altered in length or resistance.

Determine the power (in watts) consumed by the instrument with shunt when in circuit with full-scale deflection.

THE WESTON DIRECT-CURRENT VOLTMETER

The Weston direct-current movable coil voltmeter consists essentially of a light rectangular coil of copper wire usually wound upon an aluminum frame, pivoted in jeweled bearings and mounted to rotate in an annular space between the soft iron core and the specially formed pole pieces of a permanent magnet. A light tubular pointer is rigidly attached to the coil and moves over a calibrated scale.

The current is led into and from the coil by means of two spiral springs, which serve also to control its movement. This movement is due to the dynamic action between the current flowing through the coil and the magnetic field of the permanent magnet. (See Fig. 23.) The pointer becomes stationary and the coil attains a position of equilibrium when the opposing forces of the springs equal the force caused by the rotary tendency of the coil. Since the magnetic field is uniform and the torsion of the springs proportional to the deflection, the scale divisions are practically uniform.

The well-known aperiodic or "dead-beat" quality of Weston instruments is produced in this type by Foucault currents generated in the aluminum frame when rotating through the magnetic field. These Foucault currents have a sufficient influence on the movement of the frame to cause it to come to rest almost instantly and without friction.

Ball, Hauptman and Bateman, when dealing with the subject of Potential Differences,* make the following statement, which we quote not only because it is well expressed, but also since it serves excellently to describe the proper conditions under which Weston voltmeters may be used:

"It has already been stated and shown in the previous experiments that, when certain electrical generators are employed, the P.D.'s between bodies charged from such generators may remain unchanged even when these bodies are connected by a conductor. This effect may, under proper conditions, be made the basis of measurement of P.D. The instruments generally employed for the commercial measurement of P.D. are based upon this principle. It must be noted, however, that the use

* Experiment No. 107, Laboratory Experiments, 1913.

of such instruments is admissible only when the current which passes through them does not alter the P.D. between the points to which they are connected."

If, therefore, an instrument is used to measure this P.D., it should, to perform its functions properly, be so constructed that it is extremely sensitive to current.

Weston voltmeters fulfill these conditions. It is true that they are conductors and require a small current to render them operative, and that there are conditions under which they would not indicate correctly. For instance, they could not be used with marked success to determine the static charge of a Holtz machine or a Leyden jar. Neither would they correctly indicate the potential of a Zamboni dry pile,* nor should they be used to directly test the e.m.f. of a Weston standard cell.

But since Weston voltmeters require only about 1/100 ampere with full-scale deflection, there will be no appreciable fall in potential when they are connected across any commercial source of current, ranging from a light and power plant to a dry cell.

An exercise similar to the following one, on the "Study of a Voltmeter," should in our opinion form part of every laboratory course in physics.

EXPERIMENT XIV

THE STUDY OF A VOLTMETER †

Apparatus Required: Voltmeters of several types.

Voltmeters may be of the types suggested in preceding experiment, or may be electrostatic.

Examine instruments of several types and report upon the following for each:

1. The type of instrument.
2. The scale: range and graduation. Divisions—uniform or varying width. Why?

* Deschanel's Natural Philosophy, 1870.

† From "The Wiley Technical Series," Timbie's Electrical Measurements. John Wiley & Sons, Inc.

3. The construction:
    (*a*) Fixed parts: nature, material, construction and arrangement.
    (*b*) Moving parts: construction; bearings; control by which returned to zero; damping.
    (*c*) Series coils. Double-scale instruments.
4. The connections by which current enters and leaves the instrument. The circuit from binding post to binding post.
5. The resistance of the instrument. Resistance per volt.

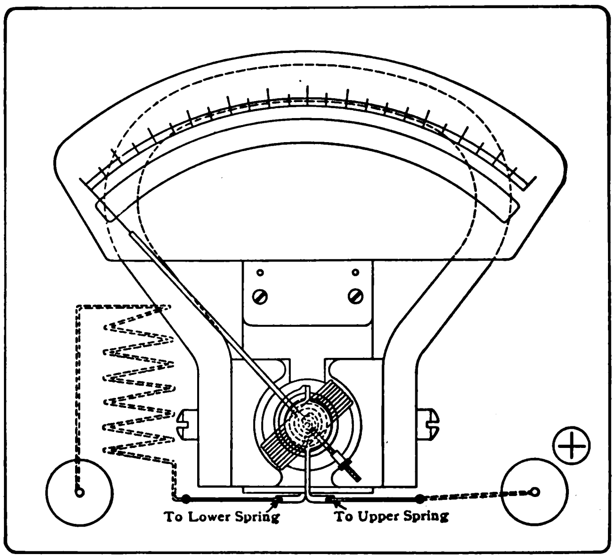


Fig. 23.

A Typical Weston Direct-current Movable-coil System.

Explain the construction and arrangement of each essential part by a separate diagram, and show by a simple diagram how the parts are assembled in the complete instrument. Show the direction of current through the instrument in each and give the reason for the deflection of the movable parts. Why does the reading indicate the difference of potential at the terminals?

State in each case whether the instrument is suited to the measurement of direct or alternating voltages and why.*

Suggestions for Further Study. Note or measure the resistance of one or more ranges of a Weston voltmeter of the movable-coil type.

Determine the current actually flowing through the instrument with full-scale deflection.

Determine the power (in watts) required to produce a full-scale deflection with different ranges.

Explain why a voltmeter the resistance of which is high (in ohms per volt) is preferable to one of low resistance.

EXPERIMENT XV

THE ACTION OF A SIMPLE CELL

Since generators and storage cells have taken the place of the primary batteries once largely used for the commercial production of current, the exercise which follows may be rated by many instructors as too abstract to deserve a place in a practical physics course. However, nearly every modern text book still retains it, and it remains for the instructor to decide whether it suffices merely to refer to Volta's discoveries, or emphasize their significance by means of an exercise which enables the student to produce current by chemical action.

Apparatus Required: Low-range, direct-current, 5-ampere Weston ammeter; low-range, direct-current, 1.5- or 3-volt Weston voltmeter; strips of sheet zinc, 2×6 inches; strips of sheet copper, 2×6 inches; glass jar, about 5 inches in diameter and 4 inches deep; 10 per cent sulphuric acid solution; mercury; copper wire.

Copper leads are to be soldered to the plates, the latter being

* For data relating to Weston movable systems, see also "Elements of Electricity," Timbie, Chap. XIV., "Physics," Mann and Twiss, page 169; "Practical Physics," Black and Davis, page 284; "Laboratory Manual," Black and Davis, page 64; "High School Physics," Carhart and Chute, page 371; "A High School Course in Physics," Gorton, page 405; "Electrical Instruments and Testing," Schneider and Hargrave, Chap. IV, "Lessons in Practical Electricity," Swoope, Lesson 18, and Weston Monograph B–4.

bent so that they may hang in the solution from the edge of the jar.

The voltmeter is first connected and deflection noted, which will be about 1 volt. See Fig. 24.

The ammeter is then substituted and deflection also noted. Current when circuit is first completed will be about 1 ampere; but since polarization rapidly sets in, the current at once decreases. Why?

Note the large number of hydrogen bubbles passing to the surface of the liquid from the zinc plate. Why?

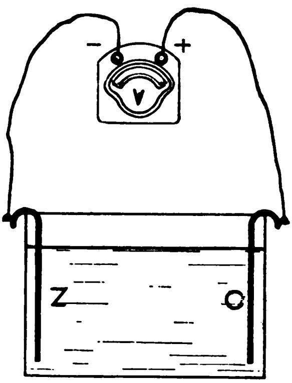


FIG. 24.

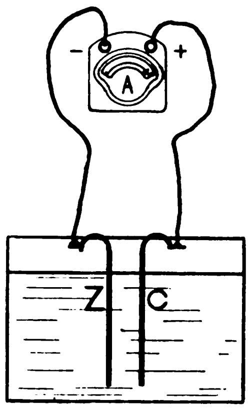


FIG. 25.

Weston Model 280 Voltmeter and Ammeter.

Substitute an amalgamated zinc plate. Note that very little hydrogen forms except when the circuit is closed, and that the current is comparatively constant. Why?

With the ammeter in circuit, decrease the distance between the zinc and copper poles, and note the increase in current. Why? See Fig. 25.

Disconnect the ammeter and try the above experiment with the voltmeter. Note that there is no appreciable difference in the e.m.f. Why?

With the plates hanging from the edge, connect both instruments successively, and note their deflections. Determine the

resistance of the circuit (cell, ammeter and leads) by the formula

$$R = \frac{E}{I}.$$

R = resistance of circuit; E = e.m.f.; I = current.

When both instruments are connected at the same time, the indicated e.m.f. of the voltmeter is much less than it is when the ammeter is not in parallel. Why?

NOTE. In making the above experiments the student may be permitted to connect the ammeter as stated, because the resistance of the cell is sufficiently high to limit the flow of current to a safe amount. He should, however, be cautioned about using an ammeter in this manner when the resistance of a cell is likely to be low, and consequently its current is large. For instance, an ordinary dry cell, when new, will have so low a resistance that it will sometimes give as much as 30 amperes for a short time when short-circuited through a Weston ammeter. Another point of importance is that the resistance of a Weston voltmeter is so high that a small decrease in the resistance of the circuit, of which it forms a part, caused by bringing the plates closer together, will have too slight an effect to materially change the total current flowing under the conditions.*

* See also Gorton's "High School Physics," Chapter XVIII; Fuller and Brownlee's "Laboratory Exercises," Experiment 68; "Physics," Mann and Twiss, page 58; "Physics Laboratory Manual," by Cavanagh, Westcott and Twining, and "Elements of Physics," by Hoadley.

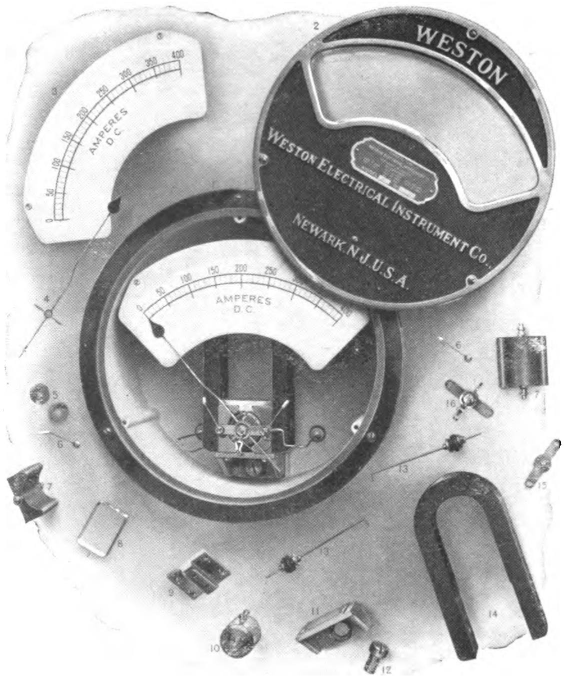


FIG. 26.—Interior View and Parts of a Standard Commercial Switchboard Ammeter

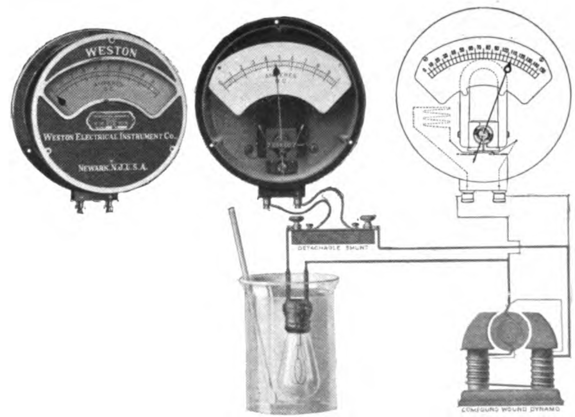


FIG. 27.—Experiment for Teaching that the Electrical Energy Required to Operate a Lamp is Converted into Heat.

The illustration shows, from left to right, a standard commercial ammeter, a standard commercial ammeter with front removed, and the internal electrical circuit of a switchboard voltmeter.

It also depicts the proper method of connecting the ammeter and voltmeter in circuit, and denotes the proper connections for the experiment.

In order to perform the experiment accurately and instructively, reliable electrical measuring instruments are essential.

Switchboard types are shown for the sake of simplicity of interior views, but portable instruments are more convenient to use if available.

The experiment can be performed with alternating-current apparatus and instruments if necessary.

Data relating to this experiment are contained in Weston Monograph B-2.

CO-OPERATORS

We publish herewith extracts from a few of the many unsolicited, but very welcome letters of commendation received since we issued Monograph B–4 and our charts, early in the spring of 1914.

We illustrate on page 71 facsimiles of the latter, but their extremely reduced dimensions cannot do justice to these artistic and useful productions.

The actual dimensions of these charts are $15\frac{3}{4} \times 17\frac{3}{4}$ inches.

As already stated, copies will be mailed to science teachers upon request, free of charge.

Bates, Lew. W., Hiram, Ohio:

"Some time ago, I received a copy of your Monograph B–4. I am very much pleased with the publication and think that I shall be able to use some things in it. I wish to thank you for the work you are doing along this line. I am anxious to know if you still have copies of the previous numbers of these publications and if so, how they may be obtained."

Beaman, Charles O., State Normal School, Brockport, N. Y.:

"Please accept my thanks for the copy of Experimental Electrical Testing which you sent me. As far as I have been able to look it over it seems to have some very fine experiments."

Black, Prof. N. Henry, Roxbury Latin School, Boston, Mass.:

"Allow me to acknowledge the receipt of Monograph B–4 on Experimental Electrical Testing.

"I have found the experiments very suggestive and I am sure other teachers will also find them helpful.

"Would you be good enough to send me two copies of Monograph B–3, which I can't seem to find anywhere."

Blair, Nathan D., Mechanics Institute, Rochester, N. Y.:

"Recently I received through the mail a copy of your Monograph B–4. After carefully examining it I would like to see the preceding ones if they are as good as B–4. I should be very glad if you will be able to send me Monographs B–1, B–2 and B–3."

Bowne, A. G., Cedar Rapids, Iowa:

"Your letter of the 8th at hand. Replying, will say that I have received your instrument catalogs, but have never

received Monographs B–1, B–2 or B–3. I have heard much about these monographs and would like to have copies of these very much if you still have them.

"Just the other day I received your Monograph B–4. I have looked it over and am very much pleased with the work set forth in it. I feel that this kind of work is worth putting before the pupils. We are planning to do more of this kind as soon as we can get equipment."

Boynton, W. P., Prof. of Physics, University of Oregon, Eugene, Ore.:

"Your two charts illustrating your switchboard instruments were delivered to the department of Physics a week or two ago, and were promptly hung up in our general laboratory. We have found them useful there, and have also taken them into the classroom to aid in explaining the construction and operation of commercial instruments.

"They are of such evident value that it is hardly necessary for me to say that we appreciate them very much indeed, and if we find them useful, with a very excellent equipment of real instruments, they ought to be even more of a boon to schools whose resources and equipment are more limited.

"While I am writing I want to express my appreciation of your miniature instruments, of which we have recently purchased a small assortment. They are the real thing, as accurate as they look, and all that is needed for practically all of our work involving commercial instruments. Personally I believe all High Schools should to a great extent select a type of experiment in Electricity which can be performed with the commercial type of instruments, and replace their galvanometers as far as possible with such instruments as these."

Bridgman, Prof. P. W., Jefferson Physical Laboratory, Harvard University, Cambridge, Mass.:

"Mr. F. H. Beals, whom I recently met in Washington, has suggested that I write to you asking for your Monographs dealing with electrical instruments for courses of instruction in colleges or secondary schools. This is a matter in which I am interested, and I would greatly prize the possession of these documents."

Burrows, J. Austin, West High School, Des Moines, Iowa.:

"We wish to acknowledge the receipt of the charts which you sent us, and thank you for the same. We highly endorse your policy in sending out these to the schools, and acknowledge their helpfulness in the development of electrical subjects in our physics class. May we go on record as wishing to encourage

such co-operation? We believe these charts and such other helps will be of real service to us.

"I am interested to know what your arrangement is regarding your Monographs. Do you send them out gratis,* or do we order them from you and pay you in return? I wish to obtain some of these from you and would appreciate your instructions as to how this may be possible.

"I wish to acknowledge the receipt of the Monographs which you sent me the latter part of last week, and please accept my thanks.

"I expect to use some of the experiments which are found therein, in my work next year, and I am sure they will be helpful to me throughout the year. I shall appreciate the receipt of any further monographs which you will get out in the near future, as there is no doubt in my mind that they are practical experiments, and many of them should be included in a practical course in physics. It may be of interest to you to know that we expect to use your instruments in our laboratory next year, as I have included six of them in my requisition for supplies for the coming year."

Cory, Merton M., Michigan Agricultural College, Dept. of Physics, East Lansing, Mich.:

"Some time ago I received one of your electrical charts. Owing to a press of college business I have neglected to acknowledge receipt of same. We appreciated the charts very much and intend to have them framed and hung in the laboratory.

"Your latest Monograph B-4, just received and it is very good. One thing disappointed me, viz., the absence of any experiments for resistance measurements by the drop of potential method.† I realize that this method is so familiar to Instructors that it is assumed the student becomes perfectly familiar with the test by measuring the resistance of one or two coils of wire.

"It is my experience with our Junior Engineers that they have only a hazy idea of how the work should be done. Therefore it seems to me that high school students should be thoroughly drilled in the use of the voltmeter and ammeter for resistance measurements.

"Trusting that you will not consider the foregoing a criticism on your very instructive monograph, but more of a lament from one who pins his faith in Ohm's Law."

* Compiler's note. Yes, in reasonable quantities we send all of our publications to instructors free of charge.

† Compiler's note. These experiments will be found in Monograph B2, a copy of which had not been received by Prof. Cory at the time of his writing.

Dry, Richard R., Technical High School, Buffalo, N. Y.:

"I have received your Monograph B–4, and am very well pleased with it. If I can in any way be of assistance in future publications of a similar character I shall consider it a privilege."

Fee, Lewis H., Science Dept. Everett High School, Everett, Wash.:

"I am in receipt of an advance copy of your Monograph B–4, Experimental Electrical Testing. I should like 4 additional copies sent to my address here.

"I believe these Monographs will supply a long felt need among the science teachers and I hope you will continue to publish the same. I have already placed the copy of B–4 in the hands of one of my laboratory sections and they are working out one of the experiments given there as a regular laboratory exercise. I shall use more of them for the same purpose."

Flanders, Milton M., Bliss Electrical School, Takoma Park Washington, D. C.:

"I beg to acknowledge with thanks the receipt of a copy of your recently published Monograph B–4. It is interesting and practical. While the nature of our course is for the most part in advance of the work covered, it seems admirably suited to the purpose for which it is intended.

"Since our students come largely from high schools where the electrical training is so often superficial and too theoretical, it should indirectly be of help to us.

"We would appreciate a few extra copies when you have them for distribution."

Gilmore, L. P., Head Dept. Science Oregon State Normal, Monmouth, Ore.

"I have at hand your Monograph B–4 and wish to say it is just the kind of work I have been looking for. You can't do too much of it. Will you send me copies of your Monographs 1, 2 and 3, as I do not have them.

"Another matter, this school is equipped with apparatus of the ninteenth century type and we are trying to replace it with up-to-date materials. I shall treat it as a favor if you will give me a list of apparatus which you think would be the type to get for a live and up-to-date course in physics. I mean chiefly such apparatus as you make. If possible have that list here by June 1st, so that we may be able to place an order early. I shall value such a favor and think I can in return promise an order. In any event I shall make a substantial effort toward that end.

"Thanking you very kindly for your most helpful monographs and information, I am."

Glenn, Earl R., Sec'y Froebel School, Gary, Ind.:

"I have carefully examined the advance copy of your most recent monograph. It is a most suggestive and helpful book for physics instructors. It is hardly necessary to add that when the equipment is purchased for the electrical courses of this school, your company will receive all orders for electrical measuring instruments."

Greenlaw, Frank M., Head of Science Dept., Rogers High School, Newport, R. I.:

"It gives me pleasure to acknowledge the receipt of set of Monographs B–1, B–2, B–3 and B–4, together with two wall charts. I am sure that these will be of much value in instruction, and expect to order in the near future a number of Weston Instruments."

Grotts, W. F., Raymond Public Schools, Raymond, Ill.:

I wish to thank you for a copy of Monograph B–4, which I have examined with interest. I think your idea is going to be of great assistance to teachers. We are always working for practical suggestions in this subject and eagerly seek helps like your Monographs.

"I would be very well pleased to receive copies of Monographs preceding B–4. If it happens that you do not have avialable copies of these please keep my name on your mailing list.".

Harkey, Theodore S., Hyde Park High School, Chicago, Ill.:

"Some time in the winter we received three or four beautiful charts of your meters of the sizes suitable for framing. At various other times we have received monographs, the last one labeled "Monograph B–4" and dated April, 1914. For these and other courtesies I want to express my heartfelt thanks.

"It seems to me that the work you are doing in the publication of these little pamphlets is the most important influence now felt throughout the schools of the United States in bringing to the attention of the teachers of science standard apparatus and the most valuable experiments that can be carried out with them. Till recently your meters were so high-priced that it was impossible for schools to think of purchasing; but the models you now have for sale are low-priced enough and accurate enough for all ordinary users. I believe you have the gratitude of the entire teaching body in the excellent work you have done in these two lines.

"In outfitting our new laboratory here, we purchased sixty-our of your new meters, Model 280."

Hazelrigg, T. Roy., Missoula County High School, Dept. of Physics, Missoula, Mont.:

"First let me thank you for Monograph No. 2, Joint Committee Series and also for B–4, Experimental Electrical Testing by students. I find that these are full of the very best of suggestions, and let me say right here that it is my intention to install a complete line of your instruments in our laboratories as soon as I can get the appropriation.

"We have been buying our supplies of the Central Scientific Company of Chicago. Will it be as cheap for us to buy our Weston instruments through them as to send direct to you?* It saves opening up two accounts.

"Have you any ideas to offer concerning the wiring of a model laboratory for the installation of your instruments? I thought that perhaps you could give me some valuable suggestions, as you perhaps have offered suggestions and sent diagrams to other schools. I think that you have entered into a great field both from an educational standpoint and also from an advertising as well. Though perhaps the latter is the ultimate aim, I am sure that we educators are glad that you have instituted the plan.

"I am starting in to plan a model laboratory for our school, though it may not come to materialize for some time. Also I have been thinking of a second-year course in Electricity, or at least with the emphasis on that branch of Physics. Can you offer any suggestions along that line or refer me to anyone? Perhaps you can offer some helpful bibliography too. You make reference to many books in your publications without definite directions as to the publishers.†

"If this letter will guide you any in your endeavors I am glad and shall be glad to co-operate with you in your campaign for '*real physics*.'"

Irish, F. M., Instructor in Physics, Tempe Normal School of Arizona, Tempe, Arizona:

"Our laboratory has received from your office two very beautifully executed charts illustrating the construction and use of standard electrical measuring instruments.

"We are certainly glad to have these charts and will find them of the greatest use in explaining the use and care of such instruments to our classes in physics, especially in view of the fact that we have purchased several of your miniature voltmeters and ammeters, and expect to add more of them to our equipment as soon as finances permit.

* Compiler's Note. Yes.

† All of the text-books to which we refer may be purchased through D. Van Nostrand & Co., N. Y., and Chicago, and other book dealers.

"The charts occupy a prominent place on the laboratory wall and attract much attention and interest.

"Please accept our thanks for these handsome aids and also for the various educational pamphlets we have received from your hands at various times, and of which we have made good use. You are rendering great assistance to instructors in these lines."

Jester, Simeon Van T., Friends' High School, Moorestown, N. J.:

"I was fortunate enough to receive your Monograph B-4 and it is the greatest help that has ever come my way. Please send me a copy of each of the monographs that have been issued.

"Please advise me about the purchase of voltmeter and ammeter and send any literature that you may have at hand."

Johnston Earl Lynd, Fort Lupton Consolidated Schools, Fort Lupton, Colo.:

"We thank you for the pair of charts, which arrived safely. We are sure that in our science department next year they will be viewed with pleasure and profit by all those students interested in the subject of electricity. We hope you may get out similar charts in the future. We also appreciate the work and care manifested in the material found in your monographs, and again we hope you will add to this series in the future."

Lowwater, Prof. F., Rockford College, Rockford, Ill.:

"Thank you for your Monograph B-4. I have not received B-1, B-2 nor B-3, but shall be pleased to do so.

"I quite appreciate your desire to work in conjunction with science teachers that the teaching of science in schools may be truly interesting to the students.

"This part of the country seems to me to be more utilitarian than the East. With most of my students (College girls) it is the essentially practical that interests them, almost solely the practical domestic. For instance, the melting-point of butter arouses real interest, whereas the melting-point of paraffin falls quite dead. I am therefore on the lookout for the experiments that will both arouse their interest and give them scientific training at the same time. In college work, of course, the latter is essential."

McClellan, John H., The Emerson School, Dept. of Physics, Gary, Ind.:

"I was certainly glad to receive your Monograph B-4. I have been using the experiments suggested with great profit to my class in Electricity. I find that laboratory work of the character outlined in your monograph adds greatly to the

interest taken in the work by the students. I should like to be placed on your mailing list for any future monographs. I hope later to be able to send you a problem or so that we have worked out.

"The great difficulty in many of the schools of this State is the lack of anything like reliable instruments for the work you outline. I believe a set of your instruments would be more valuable to a Physics Dept. than all the antiquated electrical apparatus which most laboratories possess.

"Will you please forward to my address a catalog of your miniature instruments, and oblige."

Metzger, R. D., Salem High School, Dept. Science, Salem, Ohio.:

"Monograph B–4 at hand. This is my first year here and am sorry to say that none of your previous Monographs have come to my notice. My examination of this one, B–4, shows me that I have missed some valuable aids. I certainly believe in teaching the use of instruments. We are starting to build a modern H. S. building and I hope that I may be able to influence equipping the Physics laboratory with the useful and practical modern apparatus that is absolutely needed."

Moran, Clement, Starkey Seminary, Lakemont, N. Y.:

"Your Monograph B–4 has been received. We feel that this is the best one of the series and we are sure it will be of much value to teachers and students of science.

"We are keeping them on file in our laboratory, but with the end of this year I am leaving my present position and feel that I would like to have copies that I might consider my own personally to take with me. If you can supply me with a copy of B–4 or the whole set I would appreciate the favor."

Munson, W. H., Winona, Minn.:

"The monographs came to hand to-day. Thank you for your courtesy.

"I cannot be sure how soon I shall be in the market for instruments, but I shall surely correspond with you whenever that time comes.

"I wish to express individually my appreciation of your efforts to correspond with and to co-operate with the teachers of the country in the furtherance of good work in the classroom."

Olwell, A. M., Marshall High School, Chicago, Ill.:

"Some time since I received a copy of your B–4 Monograph. I am very thankful to you for this manual.

"I have used it with good results in my laboratory work in a first year electricity class.

"Such helps as this book will do much toward dragging the

old tangent galvanometer—plunge battery physics teacher out of the rut. I wish you the greatest success in your campaign for modern practical physics instruction."

Osborn George A., Librarian, Rutgers College Library, New Brunswick, N. J.:

"We have received from the College office the copy of 'Experimental Electrical Testing by Students,' which you sent to them.

"May I ask that we be placed on your mailing list for future publications, and that they be addressed to Rutgers College Library?

"The subject is one for which we have constant calls for material, and we shall much appreciate receiving your publications."

Rayman, E. E., Lincoln High School, Cleveland, Ohio.

"I want to most cordially thank you for the Monograph B–4 which reached me this week. The strong feature of B–4 is that it is practical life, what is 'doing' to-day. I have no patience with obsolete subjects. I want what is serviceable to-day and in the future. Consequently, it gives me pleasure to be brought into communication with people who are improving present practices. Again thanking you and congratulating you on your enterprise, I am."

Rupp, R. G., Hammond High School, Hammond, Ind.:

"I note that you have just issued Monograph B–4, on Experimental Electricity Testing; I recall with pleasure the monographs which you have issued from time to time and I hope that I may receive the new one; I think you have the right idea.

"We have in our laboratory here, two each of your Model No. 280 voltmeters and ammeters; they are giving satisfaction to the very highest degree; they are so far ahead of the ordinary high school galvanometer that I would not think of returning to the latter instrument for high school use. I hope that we can add to our equipment the coming year and that the list will include some electrical apparatus."

Shannon, James D., Prof. of Physics, St. Louis University, St. Louis, Mo.:

"Allow me to thank you for the two science charts which you lately sent to us and which were referred to me. We have had them framed and they are now hung up in our physical laboratory.

"These charts have already been of real service and will

continue so to be. The one showing the interior and parts of an ammeter is especially valuable.

"Allow me to take an opportunity, which I had intended to seize before, to thank your Company for having prepared a line of instruments—ammeters, voltmeters and wattmeters—of standard grade and first-class workmanship yet of very moderate price, suitable for use in students' laboratories. Such instruments offer a solution of a very real problem that hitherto had confronted the professors and instructors in laboratories where it was desired to instruct a large number of students in modern methods of electrical measurements, and where at the same time the resources at hand are limited. Our use of these instruments has tended to strengthen the good impression produced by the first announcement of their preparation.

"Again thanking you for your charts and your Monographs for Science Teachers."

Smith, Ernest R., Vice Principal North High School, Syracuse, N. Y.:

"The latest Monograph (B–4) has arrived. I read every word at a sitting and was delighted. I believe you have made a very useful contribution to physical science teaching.

"I gladly add my testimony to the effect that Weston instruments have proven extremely satisfactory and have never given a moment's trouble. I have several different models (18 in all) in constant use, and shall order more as soon as our appropriation appears."

"Let me know if I can help the good work in any way."

Spice, Robert, Cooper Union, Dept. Chemistry, New York:

"I beg to thank you for the four Monographs which came to hand this morning.

"I wish to say that these Monographs are not only interesting and of much practical value, but they are so artistically produced that they are a pleasure to look at."

Thomas, J. M., St. Mary's College, Van Buren, Maine.

"Having come across your Monograph B–4, I have found it so much to my liking, that I must have all the others, whatever may be the charge.

"Please send me also the catalog of your instruments for students."

Turner, George M., Dept. of Physics and Chemistry, Masten Park High School, Buffalo, N. Y.:

"The advance copy of Monograph B–4 entitled 'Experimental Electrical Testing' is just at hand. It is a very helpful publication and a credit to your company. I shall be glad to obtain two or three more copies when convenient."

Wittig, Prof. Gustav, University of Alabama, College of Engineering.

"Beginning in a few weeks, I shall have a large class in physics in our summer session; judging from previous years it will number from 125 to 150, chiefly teachers in schools throughout the State. I hasten to add that they are not teachers of physics, though.

"For use with this class I should like to have extra copies of your charts, and should very much appreciate your sending me another set.

"The sixteen instruments were received in excellent condition, though we ordered them a little too late to get as full service out of them as I had hoped for this year. I enclose a hastily-made rough sketch of a wooden mount I had made in our shop for each meter. (Regret I have not time to give you a better one). Any high school with a manual training department can do the same. The dimensions are merely suggestive. When placed on a laboratory table the inclination of 45° to the horizontal makes the meter easy to read, and the stable base prevents tumbling. If you can use the sketch you are welcome to it." *

Zehetner, A. W., Instructor in Physics, Dubuque High School, Dubuque, Iowa:

"I received the voltmeter and ammeter which you designed specially for my lecture table use and cannot say too much in praise of them. A year ago I found our physical laboratory flooded with toy apparatus and was entirely lost in teaching electricity until I obtained your instruments. At present I am obliged to use the inferior instruments and am calibrating them, using yours as standards. It is surprising how the unreliability and defects of these cheaper instruments are revealed in this way. I am making use of this difficulty by giving my students several calibrating jobs, which are instructive, in more than one way, to teacher as well as student.

"We have framed the two charts you recently sent us, and they make not only excellent wall pictures in keeping with the atmosphere of the laboratory, but are proving very instructive.

"Your Monograph B–4 is also greatly appreciated. I am very glad you have entered this field and would appreciate greatly any future favors or information you have to offer."

* Compiler's note. The wooden mount referred to is intended for supporting Model 267, Weston Switchboard Voltmeters and Ammeters. It is well designed. We will send a sketch on application.